Evaluating Assembly Instruction Methods in Cell Production System by Physiological Parameters and Subjective Indices

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Abstract

Providing assembly information to support human workers has been verified to be an effective way to improve the assembly performance. However, the relationship between the assembly information format and the human workers' fatigue has not been investigated clearly. This paper is aimed to evaluate assembly instruction provided by information supporting system in fatigue aspect by using physiological measurement. The task performance and subjective rating measurements are taken into account to verify the physiological responses. The experimental results show that image and text instruction have more potential to convey the assembly information than voice instruction in this setting.

Keywords:

Cell Production System; Assembly Instruction; Mental Fatigue

1 INTRODUCTION

The traditional automated manufacturing line system is designed to produce single specific products by special machines on a mass basis. However, line production system is not flexible to adapt to the fast changing consumers' demands. Therefore, cell production system is purposed in order to overcome this demerit [1]. In the cell production system, a single human operator manually assembles each product from start to finish [2], [3]. Multi-skilled human workers amplify the flexibility of the cell production system to meet the requirements of manufacturing diversified products and quantity.

Many studies on cell production design have been done to improve collaboration between human operator and support machines [1] [3]. Assembly information support is another important research in industrial manufacturing design. In 1991, Gery had developed Electronic Performance Support System (EPSS) as an electronic information platform to capture, store and distribute knowledge from one operator to others [4]. Based on this idea, Kasvi et al. introduced the Information Support System (ISS) which can provide information based on operator's need [5]. However, most of the research objectives concentrate on the improvement of manufacturing productivity. Since human operator plays an important role in the cell production system, the fatigue condition of the human operator cannot be neglected.

Fatigue can be classified into two categories: which are physical and mental fatigue [6]. Physical fatigue causes the reduction of performance in muscular system. On the other hand, mental fatigue is observed in a sense of weariness and reduced alertness [6]. Fortunately with the development of automation system, most physical demanding jobs are diminished from manual assembly processes. Hence, this research work mainly concentrates on the mental fatigue in the production operation.

The main objective of this paper is to evaluate the effectiveness of the assembly instructions in the physiological aspect. The relation between different types of instruction and the level of fatigue experienced by workers is also presented in this paper.

In order to evaluate mental fatigue, physiological parameters, task performances and subjective indices are utilized. The methodologies, experiment setup and the formats of assembly instruction used in this study are discussed in Section 2. Section 3 explains the experimental results. Finally, the conclusion and future work are given in Section 4.

2 METHODOLOGY

2.1 Experiment Setup

Tasks

In this study, in order to examine the relation between mental fatigue and task performances, a mental workload experiment is conducted. This experiment consists of two different tasks: a pick-and-place task and a colour-count task. The pick-and-place task is chosen because of its similarity to a connector-assembly, which is a usual operation in assembly process.

For the pick-and-place task, the subjects were instructed by a predefined assembly instruction to select a coloured spherical magnet and place it on the specific location as shown in Figure 1. For as the colour-count task, the subjects calculate the total number of magnets for each colour they placed during the pick-and-place task.

Figure 3 demonstrates the experimental procedure which starts from fifteen-minute equipment preparation following by six successive sessions of 100-trial task set. Totally, the subjects are required to perform this pick-and-place task for 600 trials with five-minute break after each task session is finished.

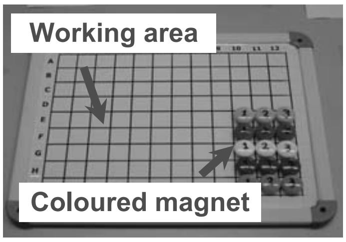
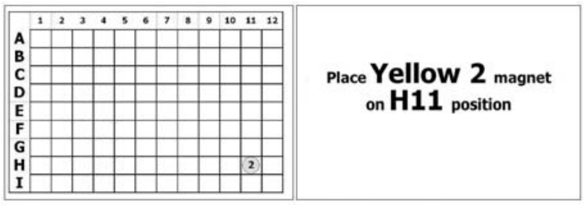


Figure 1: Working area.



(a) (b)

Figure 2: Assembly instructions.

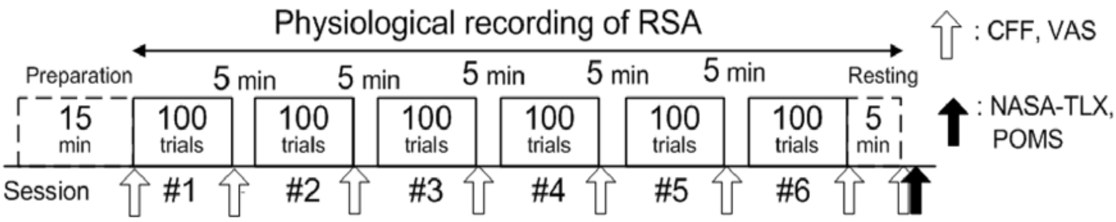


Figure 3: Experimental procedure.

Instruction types

Three different types of instruction: text, image and voice are used in this study. For image instruction experiment, the simulated image of working area is displayed on the screen of the monitor as shown in Figure 2(a). The similar setup is used in text instruction experiment. Bigger font size is used to highlight the important words as illustrated in Figure 2(b). Finally, the same sentence from text instruction is recorded into audio and played back through the speaker in the voice instruction experiment.

Subjects

Five healthy males (with ages 23±1.3) participated in this study. The experiment is conducted in two different conditions, which are actual-condition (A-condition) and control-condition (C-condition). The subjects remain sitting posture throughout the experiment.

In A-condition, the subjects have to execute both a pick-and-place task and following with a colour-count task at the same time for each instruction format (referred to: 'A-image', 'A-text' and 'A-voice'). On the other hand, only a pick-and-place task is executed during the C-condition experiment (referred to: 'C-image', 'C-text' and 'C-voice').

2.2 Mental fatigue evaluation

Interest in human fatigue has been demonstrated a long time ago and actual documentation dates as far back as World War I [6]. Many researchers who study on ergonomic field are interested in the quantitative measurement of mental fatigue. Thus, several methodologies to evaluate mental fatigue are developed in various aspects. The methods used in this paper can be categorized into task performances, subjective indices and physiological parameters.

Task performances

Task performances are calculated by the number of mistake in a pick-and-place task and the response time used in each trial.

Subjective indices

Subjective indices consist of direct or indirect queries to the individual perception of the workload encounter during any task [6]. The simplest way to estimate the mental workload is consult the human operator directly about the mental stress suffered during the task. In order to obtain subjective measurement, three following subjective indices are employed: NASA-task load index (NASA-TLX); Visual Analogue Scale (VAS) and Profiles of Mood States (POMS).

NASA-TLX classifies the degree of mental workload into six important factors which are mental demand, physical demand, temporal demand, performance, effort, and frustration [7].

VAS is the pain index of the subjects feel. POMS is used to measure mood status of the subject after performing the mental workload.

In this experiment, the subjects rate VAS during every rest period (eight times), whereas, the NASA-TLX and POMS are only conducted once at the end of experiment.

Physiological parameters

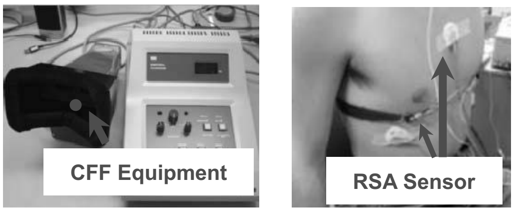
Physiological parameters are used to objectively evaluate mental fatigue in numerical figure. These kinds of measurement seem to be the most promising method for the development of a real time vital sign monitoring system.

In this experiment, the following two physiological parameters is collected during experiment to indicate mental fatigue: Critical Flicker Fusion frequency (CFF) (Figure 4 (a)); and Respiratory Sinus Arrhythmia (RSA) (Figure 4 (b)).

Critical Flicker Fusion frequency (CFF) is the frequency of an intermittent light stimulus, when it appears to be completely steady to the subject. This rate, expressed in Hz, is commonly referred to as the "threshold frequency". The CFF is widely used in the study of human mental fatigue, because it can be obtained quickly and easily. The CFF is relevant to occupational health and safety and could be interpreted as the working performance of human workers. Hence, this technique is commonly applied to analysis the level of mental fatigue.

Heart Rate Variability (HRV) is used to observe physiological condition of human operator. The high-frequency (HF) component of HRV is respiratory modulation of the heart rate. This HF component is physiologically known as Respiratory Sinus Arrhythmia (RSA) [8]. RSA refers to the slowing down of heart rate during expiration and speeding up of heart rate during inspiration. In many medical studies, RSA represents the large fluctuation of HRV that is moderated by cardiac vagal activity. From the physiological point of view, the amplitude of RSA is used for estimating mental workload. As reported by Kotani [8], the amplitude of RSA decreased as the mental workload level increased.

In this paper, this approach is utilized to evaluate the level of mental fatigue caused by different types of assembly instruction.The RSA is obtained throughout the experiment, while the CFF is measured at the beginning of each break.



(a) (b)

Figure 4: Physiological change monitoring equipment.

3 RESULT AND DISCUSSION

3.1 Task performance

Figure 5 (a) shows the average response time in each task session. Although the workload level of mental workload tasks remains constant, all subjects can execute the same task in shorter response time. This implies that the tasks are relatively simple; therefore the subjects can improve their performance in a short period of time. Therefore, the response to the same tasks became faster as the operation continued.

The image and text instruction show almost similar results while the voice instruction seems to require longer time to complete the same task.

In comparison of A-condition and C-condition, the additional mental stress caused by a colour-count task which retarded the operation was obviously observed in all formats. It can be observed that the correct rate statistically decreased in voice instruction experiment for both A-condition and C-condition.

However, the correct rate does not significantly change in image and text instruction experiment, as illustrated in Figure 5 (b). There is no distinctive difference of correct rate between A-condition and C-condition in all instruction formats.

3.2 Subjective indices

Figure 5 (c) shows the results of VAS rating score which was obtained throughout the experiment.

In this chart, the difference between A-condition and C-condition is clearly observed. The subjects seems to rate mental fatigue in the same level as the experiment proceeded. Nevertheless, there is no significant difference of image, text and voice instruction when all instructions were studied under the same condition.

The average of NASA-TLX total score in each instruction is: 64.8 ± 17.0, 70.8 ± 14.7 and 77.7 ± 16.9 for image, text and voice instruction respectively. On the other hand, the average of POMS score is: 13.8 ± 8.5 for image instruction; 13.6 ± 6.8 for text instruction and 16.8 ± 6.5 for voice instruction. The results are concerned to be relatively high where the average score for non-fatigue condition of POMS test is around 9.3 ± 6.2 [9]. In subjective rating, image and text instruction are more comfortable for delivering the assembly information to the subjects when compare to voice instruction.

3.3 Physiological parameters

Figure 5 (d) shows the change of CFF in percentage value. Opposed to other evaluation techniques, the CFF indicates that the image and text instruction cause higher mental workload than voice instruction. These results seem to have been caused by using a monitor to display the assembly information during the image and text instruction experiment, which directly affects CFF [10] [11].

The change of RSA value is illustrated in Figure 5(e). Although the decrease of RSA can be observed in some subject, the significant correlation has not been found. Figure 5 (f) is the change of RSA value that obtained from a subject. The decrease of amplitude of RSA can be observed in voice instruction experiment; however, the same inclination has not been found in image and text instruction experiment.

4 CONCLUSION AND FUTURE WORK

In order to improve the information support in cell production system, different types of assembly instruction and their effects on mental fatigue is evaluated in this study.

Two mental workload experiments are conducted to evaluate the mental fatigue by using several evaluation techniques.

The results show that image and text instruction have more potential to provide the assembly information than voice instruction. This relation can be observed in task performance measurement and subjective indices measurement. However, the same inclination has not been found in physiological measurement. In the CFF measurement, image and text instruction seemed to cause more mental fatigue than voice instruction.

Besides the improvement of assembly information support system, this study is conducted as a fundamental research to develop a real time vital sign monitoring system. Hence, the mental fatigue evaluation technique that is practical to an actual production system is the most important issue and challenging problem for future research.

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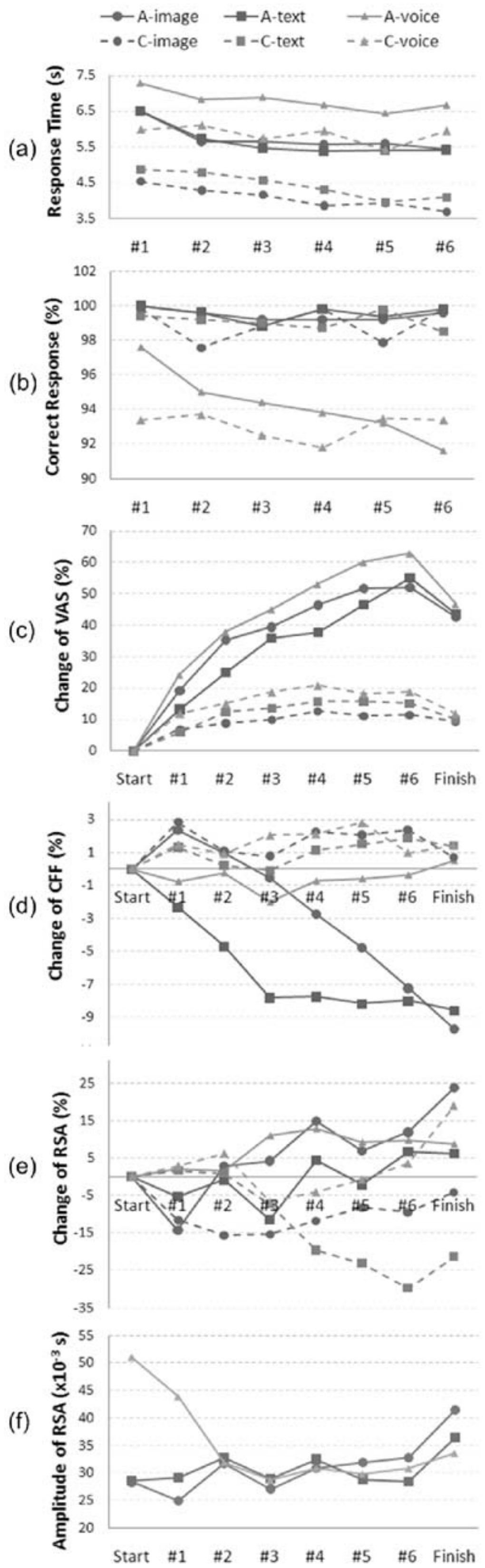

Figure 5: Experiment results.

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